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Radiation Limits for Astronauts

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In this suggested activity that has been adapted from NASAexplores,[1] students will define and calculate the radiation limits for astronauts.

Objectives:
- Describe the radiation limits for astronauts in orbit.
- Discuss engineering, operational, and dietary countermeasures for astronauts.
- Understand radiation unit conversion

Background Information:
To help answer the questions at the end of this activity, use Module 1 and the following background information.

Dose and Dose Rate
When ionizing radiation interacts with the human body, its energy is transferred to tissues, where a range of biological effects can occur. Although radiation energy can be measured in different ways, the concept of *absorbed dose,* or simply *dose,* is generally used to define the average energy deposited per unit mass inside a small volume. The volume must be large enough to contain many molecules or cells so that a statistical average of energy deposited can be taken. The *dose rate* is the rate at which this energy is deposited (also described as dose per unit time). For charged particles, the dose rate is equal to the dose per particle times the number of particles traversing the target volume per unit time.

Measuring Radiation Energy
Although there are exceptions, in general when radiation energy is transferred the deposited energy (absorbed dose) is closely related to the energy lost by the incident particles.[2] The energy imparted is expressed in the unit Gray (Gy), which is equivalent to one joule of radiation energy absorbed per kilogram of organ or tissue weight. However, it should be noted that an older unit– the *rad*–is still frequently used to express absorbed dose; one Gy is equal to 100 rad.

When measuring radiation energy another consideration is that equal doses of all types of ionizing radiation do not produce the same harmful biological effects. In particular, alpha particles (the nuclei of the helium atom) exert more damage than do beta particles, gamma rays and X-rays for a given absorbed dose depositing their energy thousands of times more effectively. While lower energy electrons can pass through the spacing between DNA strands without

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[1] http://nasaexplores.com/show_912_student_st.php?id=04032381148

[2] For example, high-energy electrons produced by charged particles traversing a cell may escape, to deposit their energy in other locations, outside the cell. At low dose rates, only one or a few particles are likely to traverse a cell. The energy deposited in the cell is less than the energy lost by the particles. However, when a large number of particles are present, then electrons generated outside the cell may compensate for those that are lost. Thus, the concept of absorbed dose incorporates many assumptions and approximations.

interacting, some high-energy heavy ions produce an ionization trail so intense that it can kill nearly every cell it traverses (see Module 2 for more detail).

To account for the difference in harmful effects produced by different types of ionizing radiation, radiation dose is expressed as *dose equivalent.* The unit of dose equivalent is the Sievert (Sv). The dose in Sv is equal to "absorbed dose" multiplied by a "radiation weighting factor" that was previously known as the Quality Factor (Q). Historically, X-rays have been used as the standard reference radiation against which all other types of radiation have been compared so the weighting factor for X-rays and gamma rays is 1. Since alpha particles cause 20 times the damage of a similar dose of X-rays or gamma rays, they have a Q of 20.

Some books use the rem to measure dose equivalent. One Sv, or 100 rem of radiation, is presumed, for the purpose of radiation protection, to have the same biological consequences as 1 Gy of X rays.

The following chart from Module 1 summarizes radiation units:

Parameter	Radioactivity	Absorbed Dose	Dose Equivalent*	Exposure (for X-rays and gamma rays only)	Energy
Definition	Rate of radiation emission (transformation or disintegration) from a radioactive substance	Energy imparted by radiation per unit mass onto an absorbing material	Expression of dose in terms of its biological effect	Quantity that expresses the ability of radiation to ionize air and thereby create electric charges that can be collected and measured	The capacity to do work
Common Units Measurement Label	Curie (Ci) 1 Ci = 37 GigaBq (this is a large amount)	Gray (Gy) Rad 1 rad = 100 ergs/g	Rem	Roentgen (R)	Joule (J)
International System of Units (SI) Measurement Label	Becquerel (Bq) 1 Bq = 1 event of radiation emission per second (this is a very small amount)	Gray (Gy) 1 Gy = 100 rad	Sievert (Sv) 1Sv=100 rem (this is a large dose) 1 Gy air dose equivalent = 0.7 Sv $1 R \approx 10$ mSv of tissue dose	Coulomb/kilogram (C/kg) $1 R = 2.58 \times 10^{-4}$ C/kg air	Electronvolts (eV)

*Dose Equivalent = Absorbed Dose x Quality Factor (Q), where Q depends on the type of radiation (Q = 1 for gamma, X-ray, or beta radiation; Q = 20 for alpha radiation)

Research Question:

How does the amount of radiation astronauts receive in space compare to radiation exposures on Earth?

Materials:
Calculators
Radiation Exposure Chart
Module 1

Methods:
Ask the students to read the background material and use the following chart[3] to answer the questions listed below.

Radiation Exposure Limits for Astronauts and the General Public (in Sv)				
Type of person	**Time period**	**Organs (Sv)**	**Eye (Sv)**	**Skin (Sv)**
Astronauts	30-day	0.25	1.0	1.5
	Annual	0.5	2.0	3.0
	Career	1.0-4.0	4.0	6.0
Occupational Exposure	Annual	0.05	0.15	0.5
General Public	Annual	0.001	0.015	0.05

Procedure

(1) During a hypothetical 10-day mission on the Space Shuttle, astronauts are exposed to an average organ dose of approximately 0.433 rem. Assuming a person of the general public on Earth received a 0.001 Sv organ dose per year every year, how long would it take him or her to receive the same amount of organ radiation exposure on Earth as the shuttle astronaut receives?

(2) How many times greater is the annual allowable limit for an astronaut's organ dose than the annual allowable limit for occupational worker's organ dose? How many times greater is the astronaut's annual allowable limit for organ dose than the general public's annual allowable limit for organ dose?

(3) Over an entire 10-day shuttle mission, an astronaut's skin was exposed to a total of 7.86 rem. What would be the average skin exposure per day? If this exposure rate was the same for an entire year, how much dose would an astronaut receive? Would this exceed the 30-day skin dose limit? Does it exceed the annual dose limit? Why is the allowable limit for organ exposure for astronauts so much less than the skin exposure (in other words, why is the skin allowed to have more radiation than organs beneath the skin)?

(4) How many times greater is the annual allowable limit for an astronaut's eye dose than the annual allowable limit for occupational worker's eye dose? How many times greater is the astronaut's annual allowable limit for eye dose than the general public's annual allowable limit for eye dose?

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[3] Adapted from http://srag-nt.jsc.nasa.gov/RadDocs/TM104782/techmemo.htm

(5) Will astronauts affected by the increased radiation influence the genetic stability of the human population?

(6) Each individual astronaut has agreed to be exposed to this extra radiation, knowing that space travel for now cannot avoid it. Why do you think they would be willing to do this?

(7) How does NASA keep track of the radiation exposure to each astronaut?

(8) Assume that a CT scan of your chest exposes your skin to approximately 5.3 mSv (1 Sv = 1000 mSv) of radiation. How many rem is 5.3 mSv? If we assume that over an entire 8-day shuttle mission, an astronaut's skin is exposed to a total of 5.59 mSv, how many days in orbit would the CT scan equate to for astronauts?

(9) NASA limits the amount of radiation exposure per year for astronauts. Why do you suppose there is a need for annual and career limits too?

Answers to the questions:
(1) Hint: Convert the astronaut exposure to Sv, and divide by the Sv/year. The answer is 4.33 years.

(2) 10 times greater. 500 times greater.

(3) 0.786 rem skin dose per day is an average of 286.89 rem skin dose per year. It exceeds the 30-day limit but not the annual limit. The skin is the first line of defense. It will begin to absorb radiation to protect the rest of the body. If organs are receiving high doses, it means than the surface of the body is receiving an even higher dose, which would be extremely damaging.

(4) 13.333 times greater, and 133.33 times greater

(5) Possibly, but the entire population of people that are directly involved space activities is of limited size, so the effects will be very small, if any.

(6) Student answers will vary. One possibility, the benefit of spaceflight exceeds the risk involved.

(7) NASA keeps careful counts of time in orbit, number of missions, radiation levels before and after each mission.

(8) 5.3 mSv = 0.53 rem, approximately 7.58 days.

(9) Each mission may fall below the dose limits, but over time the amount may become dangerously high. The effects of radiation are cumulative.

Resources:
Information in this activity was adapted from content found at:
http://nasaexplores.com/show_912_teacher_st.php?id=04032381148